U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-296 787

Phenol: Ambient Water Quality Criteria

(U.S.) Environmental Protection Agency, Washington, DC

1978

PB 296787

P H E N O L

Ambient Water Quality Criteria

Criteria and Standards Division
Office of Water Planning and Standards
U.S. Environmental Protection Agency
Washington, D.C.

REPRODUCED BY
NATIONAL TECHNICAL
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U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

BIBLIOGRAPHIC INFORMATION

PB-296 787

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PERFORMER: Environmental Protection Agency, Washington, DC. Criteria and Standards Div.

Section 304(a) of the Clean Water Act (33 U.S.C. 1314(a)), requires EPA to publish and periodically update water quality criteria. These criteria are to reflect the latest scientific knowledge on the identifiable effects of pollutants on public health and welfare, aquatic life, and recreation. This report presents water quality criteria for phenol. It presents concentration criteria for the protection of fresh water and saltwater aquatic life. It presents 'safe' concentrations for humans, and in the case of suspect or proven carcinogens, gives various levels of incremental cancer risk. A section 304(a) water quality criterion is a qualitative or quantitative estimate of the concentration of a water constituent or pollutant in ambient waters which, when not exceeded, will ensure a water quality sufficient to protect a specified water use. Under the Act a criterion is a scientific entity, based solely on data and scientific judgement. It does not reflect consi....

KEYWORDS: *Water quality, *Toxicology, *Phenol, *Toxic substances, *Water pollution effects(Humans).

Available from the National Technical Information Service, Springfield, Va. 22161

PRICE CODE: PC A05/MF A01

CRITERION DOCUMENT

PHENOL

CRITERIA

Aquatic Life

For phenol the criterion to protect freshwater aquatic life as derived using the Guidelines is 600 µg/l as a 24-hour average, and the concentration should not exceed 3,400 µg/l at any time.

For saltwater aquatic life, no criterion for phenol can be derived using the Guidelines, and there are insufficient data to estimate a criterion using other procedures.

Human Health

For the protection of human health from phenol ingested through water and through contaminated aquatic organisms the concentration in water should not exceed 3.4 mg/l.

For the prevention of adverse effects due to the organoleptic properties of chlorinated phenols inadvertently formed during water purification processes, the phenol concentration in water should not exceed 1.0 µg/l.

PHENOL

Introduction

Phenol is a large volume industrial chemical produced almost entirely as an intermediate for the preparation of other chemicals. These include synthetic polymers such as phenolic resins, bis-phenol and caprolactam plastics intermediates, and chlorinated and alkylated phenols.

Phenol, occasionally referred to as "carbolic acid", is a monohydroxybenzene which is a clear, colorless (light pink when impurities are present), hygroscopic, deliquescant, crystalline solid at 25°C (Manufacturing Chemist Assoc. 1964; Kirk and Othmer, 1963; Weast, 1974). It has the empirical formula C_6H_6O, a molecular weight of 94.11, a specific gravity of 1.071 at 25°C/4°C and a vapor pressure of 0.3513 mm Hg at 25°C (Patty, 1963; Manufacturing Chemists Assoc. 1964; Am. Ind. Hyg. Assoc. 1957; Sax, 1975). Phenol has a melting point of 43°C and a boiling point of 182°C at 760 mm Hg (Weast, 1974).

Phenol has a water solubility of 6.7 g/100 ml at 16°C and is soluble at all proportions in water at 66°C. It is also soluble in relatively non-polar solvents such as benzene, petrolatum, and oils (Patty, 1963, Kirk and Othmer, 1963; Weast, 1974.)

Due to the electronegative character of the phenyl group, phenol exhibits weakly acidic properties. It possesses a pKa of 9.9 to 10.0 and readily reacts with strong bases to form salts called phenoxides (Weast, 1974; Kirk and Othmer,

1963). Phenoxides exist in highly alkaline aqueous solutions and many, particularly the sodium and potassium salts, are readily soluble in water.

Natural phenol is produced by the distillation of coal tar, although this source constitutes only one to two percent of total phenol production (Kirk and Othmer, 1963). The cumene process represents the most popular route of phenol production and involves two basic steps. Cumene is oxidized to cumene hydroperoxide with air in the presence of an alkali catalyst and is subsequently cleaved to phenol and acetone with the aid of a sulfuric acid catalyst (Cook, 1977). Other methods of commercial production include the toluene oxidation process and the benzene sulfonation process (Faith, et al. 1975). In the former process, toluene is oxidized to benzoic acid and reduced to phenol, using a copper catalyst. The latter method involves the sulfonation of benzene to benzene-sulfonic acid, its neutralization with sodium sulfite or carbonate to form sodium benzenesulfonate and the subsequent reaction of this compound with fused caustic soda at high temperatures. The sodium phenate or sodium salt is then acidified with sulfur dioxide to form the phenol (Faith, et al. 1975). This purity of most synthetic phenols is greater than 99.5 percent, while the purity of natural sources ranges from 80 to 82 percent and 90 to 92 percent, depending upon the source and method of production. The commercial products generally contain an impurity which changes the melting point (Spector, 1956; Stecher, 1968).

Phenol or phenolic wastes also are produced during the coking of coal, distillation of wood, operation of gas works and oil refineries, livestock dips, human and animal wastes, and microbiological decomposition of organic matter (Bulick, 1950; Mischonsniky, 1934).

Phenol undergoes oxidation to a variety of products, such as the benzenediols, benzenetriols, and derivatives of diphenyl and diphenylene oxide, depending on the oxidizing agent and conditions (Kirk and Othmer, 1963). However, Phenol may be biochemically hydroxylated to ortho- and paradihydroxybenzenes and readily oxidized to the corresponding benzoquinones. These may in turn react with numerous components of industrial waters or sewage such as mercaptans, amines or the -SH or -NH groups of proteins. In the absence of these compounds, the quinones, especially the ortho-isomers, can be quickly destroyed by hydrolytic oxidizing reactions (Stom, 1975).

The hydroxyl group of phenol imparts a high degree of reactivity to the phenyl ring, particularly the ortho- and para positions. Phenol has been shown to be highly reactive to chlorine in dilute aqueous solutions over a wide pH range (Carlson and Caple, 1975; Middaugh and Davis, 1976). The chlorination of phenol in aqueous soultions to form 2-chloro-, 4-chloro-, or higher chlorophenols has been demonstrated under conditions similar to those used for disinfection of waste water effluents (Aly, 1968; Barnhart and Campbell, 1972) and represents a potential amplification

of the organoleptic problems associated with phenol contamination. Synthesis of 2-chlorophenol within one hour in aqueous solutions containing as little as 10 mg/l phenol and 20 mg/l chlorine has been reported (Barnhart and Campbell, 1972). Other studies have reported the formation of up to 1.7 ug/l 2-chlorophenol and other chlorinated compounds during the chlorination or sewage effluents and power plant cooling waters (Jolly, 1973, Jolly, et al. 1975). These observations are highly significant in view of the ability of the chlorophenols to cause tainting of fish flesh at lower concentrations. The property of 2-chlorophenol and 2,4-dichlorophenol to impart an odor to water and a taint to the flesh of aquatic organisms at concentrations varying from 0.33 µg/l to 15.0 µg/l and 0.65 µg/l to 10.0 µg/l, respectively, has been reported (see 2-chlorophenol and 2,4-dichlorophenol criterion documents). This represents a possible potentiation in the organoleptic properties of phenol in water by approximately 30,000-fold.

The photooxidation of phenol in water at alkaline pH has been studied. Irradiation with a mercury arc lamp produced several intermediate compounds and p-benzosemiquinone as the final product (Tomkiewicz, et al. 1971; Cocivera, et al. 1972). Audureau, et al. (1976) studied the photooxidation of phenol with ultraviolet irradiation (253.7 nm) and concluded that the reaction initially leads to the formation of a complex mixture of tri- and tetrahydroxybiphenyls, quinones and diphenols. Aqueous phenol solutions irradiated with sunlight for seven days were reported to degrade to hydroquinone and pyrocatechol (Perel'shtein and Kaplin, 1968).

Subsequent irradiation of pyrocatechol with sunlight for seven days yielded pyrogallol. The end products of photodecomposition were reported to be humic acids. Conversely, similar studies utilizing natural sunlight as the source of irradiation indicated that phenol concentrations in solutions of pure water remained unchanged after ten days (Wilbaut-Isebree, 1964). However, phenol degradation did occur in industrial sewage effluents and led to the conclusion that unidentified microorganisms, not sunlight, were responsible for the destruction of phenol.

The microbiological degradation of phenol has been widely studied. Bayly, et al. (1966) reported the conversion of phenol to catechol by Pseudomonas putida. Neujahr and Varga (1970) observed the oxidation of phenol by both intact cells and extracts of the microorganism, Trichosporon cutaneum. Buswell and Twomey (1975) and Buswell (1975) demonstrated the ability of the thermophilic bacteria, Bacillus stearothermophilus, to catabolize phenol. In these studies, the bacteria first converted phenol to catechol and subsequently cleaved the aromatic ring to form 2-hydroxymuconic semialdehyde. In view of the fact that phenol represented the primary carbon source provided to isolated and adapted microorganisms in these studies, the importance or microbiological degradation within the environment remains unclear.

Although phenol appears to be less toxic than the chlorinated phenols and certain other substituted phenols, its toxicity to microorganisms, plants, aquatic organisms and mammals, including man, has been demonstrated. Phenol also

has been reported to exhibit carcinogenic activity in mice. These findings, together with potential pollution from waste sources and the possible chlorination of phenol present in drinking water sources, indicate that phenol is potentially hazardous to aquatic and terrestrial life.

Information concerning the presence and persistence, and fate of phenol in the environment is incomplete or not available. A limited number of studies indicate that phenol does not bioconcentrate appreciably in aquatic organisms.

The widespread use of phenol as an important chemical intermediate, the generation of phenolic wastes by industry and agriculture, and the toxicological and organoleptic properties indicate its importance in potential point source and nonpoint source water contamination.

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AQUATIC LIFE TOXICOLOGY*

FRESHWATER ORGANISMS

Introduction

Phenol is predominantly used as an intermediate in a wide variety of chemical processes. These processes produce epoxy and phenolic resins, pharamaceuticals, germicides, fungicides, slimicides, herbicides, dyes, and a variety of industrially important acids. The phenol molecule easily substitutes in the environment to form compounds such as halophenols, which may be more toxic than the parent molecule. Phenol is degraded by a number of bacteria and fungi that may cause slime growths and depress dissolved oxygen in the receiving waters, thus lowering water quality.

Although an abundance of data on the acute toxicity of phenol to fish and invertebrate species and plants is available, the chronic toxicity data are limited to one test on Daphnia magna. Toxicity testing on the same species by different researchers in different waters produced LC50 values which varied widely. This

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*The reader is referred to the Guidelines for Deriving Water Quality Criteria for the Protection of Aquatic Life [43 FR 21506 (May 18, 1978) and 43 FR 29028 (July 5, 1978)] in order to better understand the following discussion and recommendation. The following tables contain the appropriate data that were found in the literature, and at the bottom of each table are the calculations for deriving various measures of toxicity as described in the Guidelines.

indicates that water quality parameters such as pH, hardness, temperature, and others may alter the toxicity of the compound.

Acute Toxicity

Acute toxicity data for 13 species of fish are included in Table 1. Rainbow trout, the most sensitive fish species tested, had the lowest adjusted LC50 concentration of 2,624 µg/l (Cairns, et al. 1978). The least sensitive species was the goldfish with adjusted LC50 concentrations as high as 93,720 µg/l (Cairns, et al. 1978).

There is a wide range of interspecific variability in addition to the wide range of intraspecific sensitivity previously mentioned. Adjusted LC50 concentrations for rainbow trout varied from 2,624 µg/l (Cairns, et al. 1978) to 11,600 µg/l (Fogels and Sprague, 1977). The fathead minnow, a commonly used test species, had adjusted LC50 concentrations that varied from 17,494 µg/l (Pickering and Henderson, 1966; Mattson, et al. 1976) to 67,500 µg/l (U.S. EPA, 1978b). The bluegill, another commonly used test species, had adjusted LC50 concentrations from 6,287 µg/l (Cairns and Scheier, 1959) to 28,116 µg/l (Cairns, et al. 1978).

Several studies showed the effects of temperature on phenol toxicity. Brown, et al. (1967a, b) demonstrated an inverse relationship between survival time and temperature when rainbow trout were exposed to phenol at 6.3°, 11.8°, and 18.1°C. The adjusted LC50 concentrations at these respective temperatures are 3,106, 4,601, and 5,636 µg/l. The same relationship was shown by Cairns, et al. (1978) with the golden shiner; however, these same investigators found rainbow trout to be more sensitive at 5°C with an adjusted LC50 concentration of 2,624 µg/l than at 12° and 18°C

with adjusted LC50 concentrations of 5,155 µg/l and 5,295 µg/l, respectively. Ruesink and Smith (1975) conducted tests on fathead minnows at 15° and 25°C and found 96-hour LC50 values of 36,000 µg/l and 24,000 µg/l.

Because of the wide variation in species sensitivity, it appears that division by the appropriate sensitivity factor is necessary to derive a Final Fish Acute Value for phenol to protect the more sensitive salmonid species. Although the adjusted LC50 values for rainbow trout from three tests conducted under static or renewal conditions (McLeay, 1976; Brown, et al. 1967a, b; Cairns, et al. 1978) were slightly lower than the Final Fish Acute Value of 4,000 µg/l, all adjusted LC50 values for rainbow trout in flow-through measured tests (Mitrovic, et al. 1968; U.S. EPA, 1978b; Fogels and Sprague, 1977) are above the Final Fish Acute Value. Since the Final Fish Acute Value is protective of the most sensitive fish species under flow-through conditions, this suggests a reasonable fit of the data to the procedures in the Guidelines.

Toxicity data for the 13 invertebrate species, including rotifers, annelids, snails, clams, cladocerans, conchostracans, and isopods, are listed in Table 2. Tests conducted by Alekseyev and Antipin (1976) are an indication of the relative sensitivity of several invertebrate species since these tests were conducted using the same water and similar test methods for all species. They found adjusted LC50 concentrations ranging from 5,463 µg/l for the adult isopod, Asellus aquaticus, to 284,084 µg/l for the clam, Sphaerium corneum. Data in Table 2 indicate that snails

and clams are among the least sensitive invertebrate species to phenol while the cladocerans are among the more sensitive.

Cairns, et al. (1978) determined adjusted LC50 concentrations that are up to 19 times higher than the LC50 concentrations reported by the other five researchers who tested cladocerans. Cairns, et al. (1978) tested phenol at different temperatures with the same water quality parameters and found fairly uniform LC50 concentrations that ranged from 96,800 µg/l to 110,000 µg/l for Daphnia magna and 86,900 µg/l to 102,300 µg/l for Daphnia pulex. The mean of adjusted LC50 concentrations for all other cladoceran tests was 25,071 µg/l with a range of 5,929 µg/l to 84,700 µg/l for Daphnia magna (Dowden and Bennett, 1965). Dowden and Bennett (1965) found young Daphnia magna to be about three times more sensitive than adults.

The range of species sensitivity displayed in Table 2 (the highest adjusted LC50 divided by the lowest) is 52 times. This indicates that division by a sensitivity factor is advisable to obtain a Final Invertebrate Acute Value that will protect the more sensitive invertebrate species. The Final Invertebrate Acute Value of 3,400 µg/l is only 1.7 times lower than the lowest adjusted acute value, which indicates a reasonable fit of the data to the procedures in the Guidelines. Since 3,200 µg/l is lower than the Final Fish Acute Value, it becomes the Final Acute Value for freshwater aquatic life.

Chronic Toxicity

No data dealing with chronic effects of phenol on freshwater fish are available, but one chronic test with an invertebrate

species was found (Table 3). In a life cycle chronic test (U.S. EPA, 1978a) a chronic value concentration of 3,074 µg/l was determined for the cladoceran Daphnia magna. The adjusted 48-hour EC50 concentration for daphnids from the same study was 9,995 µg/l. The range of sensitivity for invertebrate species cannot be determined from chronic data, but may be inferred from acute toxicity data (Table 2). With the possible exception of data determined by Cairns, et al. (1978), it appears that Daphnia magna is one of the more sensitive invertebrate species to phenol. However, because of the large variation in sensitivity of invertebrate species to various toxicants and because the chronic value for phenol is close to the adjusted LC50 concentrations for several invertebrate species, reduction of the chronic value by the sensitivity factor would yield a Final Invertebrate Chronic Value that would be more likely to protect sensitive invertebrate species for extended exposure periods. Thus, the Final Invertebrate Chronic Value of 600 µg/l becomes the Final Chronic Value for phenol since that value is lower than the lowest values derived from chronic data for plants (Table 4) and from other data (Table 5).

Plant Effects

Plants are relatively insensitive to phenol exposure, and all reported plant effects are much higher than the Final Chronic Value of 600 µg/l. Reynolds, et al. (1975) reported up to 66 percent cell number reduction with the alga, Selenastrum capricornutum (Table 4), after two days at 24°C at 20,000 µg/l. There are two values given for chlorosis (the destruction of chlorophyll). Huang and Gloyna (1968) reported the complete destruction

of chlorophyll in Chlorella pyrenaidosa in two days at 1,500,000 µg/l, and Blackman, et al. (1955) reported an EC50 concentration of 1,504,000 µg/l based on chlorosis in the duckweed Lemna minor. Simon and Blackman, (1953) found a 50 percent reduction in growth at 479,400 µg/l, which was approximately three times lower than the concentration causing chlorosis in the same species. The diatom, Nitzschia linearis, had a 50 percent growth reduction in 120 hours at 258,000 µg/l (Patrick, et al. 1968).

The Final Plant Value is 20,000 µg/l, based on data of Reynolds, et al. (1975).

Residues

Table 5 contains bioconcentration data on phenol for goldfish. However, since no maximum permissible tissue concentration is available for phenol, no Residue Limited Toxicant Concentration can be calculated. The bioconcentration factors calculated for phenol (Kobayashi, et al. 1976; Kobayashi and Akitake, 1975) ranged from 1.2 to 2.3. Bioconcentration factors this low indicate that no residue problem should occur from exposure to phenol.

CRITERION FORMULATION

Freshwater - Aquatic Life

Summary of Available Data

The concentrations below have been rounded to two significant figures.

Final Fish Acute Value = 4,000 µg/l

Final Invertebrate Acute Value = 3,400 µg/l

Final Acute Value = 3,400 µg/l

Final Fish Chronic Value = not available

Final Invertebrate Chronic Value = 600 µg/l

Final Plant Value = 20,000 µg/l

Residue Limited Toxicant Concentration = not available

Final Chronic Value = 600 µg/l

0.44 x Final Acute Value = 1,500 µg/l

The maximum concentration of phenol is the Final Acute Value of 3,400 µg/l and the 24-hour average concentration is the Final Chronic Value of 600 µg/l. No important adverse effects on freshwater aquatic organisms have been reported to be caused by concentrations lower than the 24-hour average concentration.

CRITERION: For phenol the criterion to protect freshwater aquatic life as derived using the Guidelines is 600 µg/l as a 24-hour average, and the concentration should not exceed 3,400 µg/l at any time.

Table 1. Freshwater fish acute values for phenol

Organism	Bioassay Method*	Test Conc.**	Time (hrs)	LC50 (ug/l)	Adjusted LC50 (ug/l)	Reference
Rainbow trout (juvenile), Salmo gairdneri	R	U	96	5,020	2,744	McLeay, 1976
Rainbow trout (juvenile), Salmo gairdneri	R	M	48	5,400	3,106	Brown, et al. 1967b
Rainbow trout (juvenile), Salmo gairdneri	R	M	48	8,000	4,601	Brown, et al. 1967b
Rainbow trout (juvenile), Salmo gairdneri	R	M	48	9,800	5,636	Brown, et al. 1967b
Rainbow trout (juvenile), Salmo gairdneri	FT	M	48	7,500	6,075	Mitrovic, et al. 1968
Rainbow trout (juvenile), Salmo gairdneri	FT	M	96	8,900	8,900	U.S. EPA, 1978b
Rainbow trout (yearling), Salmo gairdneri	R	M	48	9,400	5,406	Brown & Dalton, 1970
Rainbow trout, Salmo gairdneri	S	M	24	5,600	2,624	Cairns, et al. 1978
Rainbow trout, Salmo gairdneri	S	M	24	11,000	5,155	Cairns, et al. 1978
Rainbow trout, Salmo gairdneri	S	M	24	11,300	5,295	Cairns, et al. 1978
Rainbow trout, Salmo gairdneri	FT	M	96	11,600	11,600	Fogels & Sprague, 1977
Brook trout (juvenile), Salvelinus fontinalis	S	U	24	11,700	4,222	Miller & Ogilvie, 1975
Goldfish, Carassius auratus	S	M	24	200,000	93,720	Cairns, et al. 1978

Table 1. (Continued)

Organism	Bioassay Method*	Test Conc.**	Time (hrs)	LC50 (ug/l)	Adjusted LC50 (ug/l)	Reference
Goldfish, Carassius auratus	S	U	96	44,490	24,323	Pickering & Henderson, 1966
Golden shiner, Notemigonius crysoleueus	S	M	24	129,000	60,449	Cairns, et al. 1978
Golden shiner, Notemigonius crysoleueus	S	M	24	35,000	16,401	Cairns, et al. 1978
Fathead minnow (adult), Pimephales promelas	S	U	24	65,340	23,576	Jenkins, 1960
Fathead minnow (adult), Pimephales promelas	FT	M	96	67,500	67,500	U.S. EPA, 1978b
Fathead minnow, Pimephales promelas	S	U	96	34,270	18,735	Pickering & Henderson, 1966
Fathead minnow, Pimephales promelas	S	U	96	32,000	17,494	Pickering & Henderson, 1966
Fathead minnow (adult), Pimephales promelas	FT	M	96	36,000	36,000	Ruesink & Smith, 1975
Fathead minnow (adult), Pimephales promelas	FT	M	96	24,000	24,000	Ruesink & Smith, 1975
Fathead minnow, Pimephales promelas	FT	M	96	28,780	28,780	Phipps, et al. Manuscript
Fathead minnow, Pimephales promelas	S	U	96	32,000	17,494	Mattson, et al. 1976
Walking catfish, Clarias batrachus	R	U	48	31,500	13,949	Mukherjee & Bhattacharya, 1974
Channel catfish (juvenile), Ictaluras punctatus	S	U	96	16,700	9,130	Clemens & Sneed, 1959
Flagfish, Jordanella floridae	FT	M	96	36,300	36,300	Fogels & Sprague, 1977
Mosquitofish, Gambusia affinis	S	M	96	26,000	18,460	Nunogawa, et al. 1970

Table 1. (Continued)

Organism	Bioassay Method*	Test Conc.**	Time (hrs)	LC50 (ug/l)	Adjusted LC50 (ug/l)	Reference
Guppy, Poecilia reticulatus	S	M	96	31,000	22,010	Nunogawa, et al. 1970
Guppy, Poecilia reticulatus	S	U	96	39,190	21,425	Pickering & Henderson, 1966
Mollies (adult), Mollienesia latipinna	S	U	25	63,000	22,732	Dowden & Bennett, 1965
Mollies (adult), Mollienesia latipinna	S	U	50	22,000	9,742	Dowden & Bennett, 1965
Bluegill, Lepomis macrochirus	S	U	96	13,500	7,380	Patrick, et al. 1968
Bluegill (juvenile), Lepomis macrochirus	R	M	96	19,300	13,703	Trama, 1955
Bluegill, Lepomis macrochirus	S	U	96	13,500	7,380	Cairns & Scheier, 1959
Bluegill, Lepomis macrochirus	S	U	96	20,000	10,934	Cairns & Scheier, 1959
Bluegill, Lepomis macrochirus	S	U	96	11,500	6,287	Cairns & Scheier, 1959
Bluegill (juvenile), Lepomis macrochirus	R	U	48	22,200	9,831	Lammering & Burbank, 1960
Bluegill (juvenile), Lepomis macrochirus	S	U	48	19,000	8,414	Turnbull, et al. 1954
Bluegill, Lepomis macrochirus	S	M	24	60,000	28,116	Cairns, et al. 1978
Bluegill, Lepomis macrochirus	S	U	96	23,880	13,055	Pickering & Henderson, 1966
Mozambique mouthbrooder, Tilapia mossambica	S	M	96	19,000	13,490	Nunogawa, et al. 1970

* S = static, R = renewal, FT = flow-through
** U = unmeasured, M = measured
Geometric mean of adjusted values = 15,617 µg/l $\frac{15,617}{3.9}$ = 4,000 µg/l
Lowest value from a flow-through test with measured concentrations = 6,100 µg/l

Table 2. Freshwater invertebrate acute values for phenol

Organism	Bioassay Method *	Test Conc. **	Time (hrs)	LC50 (ug/l)	Adjusted LC50 (ug/l)	Reference
Rotifer, Philodina acuticornis	S	U	96	248,000	210,056	Buikema, et al. 1974
Rotifer, Philodina acuticornis	S	M	48	300,000	141,900	Cairns, et al. 1978
Rotifer, Philodina acuticornis	S	M	48	282,000	133,386	Cairns, et al. 1978
Rotifer, Philodina acuticornis	S	M	48	245,000	115,885	Cairns, et al. 1978
Rotifer, Philodina acuticornis	S	M	48	205,000	96,965	Cairns, et al. 1978
Rotifer, Philodina acuticornis	S	M	48	292,000	138,116	Cairns, et al. 1978
Annelid, Aeolosoma headleyi	S	M	48	360,000	170,280	Cairns, et al. 1978
Annelid, Aeolosoma headleyi	S	M	48	351,000	166,023	Cairns, et al. 1978
Annelid, Aeolosoma headleyi	S	M	48	381,000	180,213	Cairns, et al. 1978
Annelid, Aeolosoma headleyi	S	M	48	356,000	168,388	Cairns, et al. 1978
Annelid, Aeolosoma headleyi	S	M	48	341,000	161,293	Cairns, et al. 1978
Snail, Limnaea stagnalis	R	U	48	350,000	127,474	Alekseyev & Antipin, 1976
Snail, Nitrocris sp.	S	M	48	389,000	183,997	Cairns, et al. 1978
Snail, Nitrocris sp.	S	M	48	351,000	166,023	Cairns, et al. 1978
Snail, Nitrocris sp.	S	M	48	353,000	166,969	Cairns, et al. 1978

Table 2. (Continued)

Organism	Bioassay Method *	Test Conc.**	Time (hrs)	LC50 (ug/l)	Adjusted LC50 (ug/l)	Reference
Snail, *Nitrocris sp.*	S	M	48	360,000	170,280	Cairns, et al. 1978
Snail, *Nitrocris sp.*	S	M	48	391,000	184,943	Cairns, et al. 1978
Snail (adult), *Physa fontinalis*	R	U	48	320,000	116,547	Alekseyev & Antipin, 1976
Snail (juvenile), *Physa fontinalis*	R	U	48	260,000	94,695	Alekseyev & Antipin, 1976
Snail, *Physa heterostropha*	S	U	96	94,000	79,618	Patrick, et al. 1968
Clam, *Sphaerium corneum*	R	U	48	780,000	284,084	Alekseyev & Antipin, 1976
Cladoceran, *Daphnia longispina*	R	U	48	14,000	11,858	Alekseyev & Antipin, 1976
Cladoceran, *Daphnia magna*	S	U	48	9,600	8,131	Kopperman, et al. 1974
Cladoceran, *Daphnia magna*	S	U	48	11,800	9,995	U.S. EPA, 1978a
Cladoceran, *Daphnia magna*	S	U	48	100,000	84,700	Dowden & Bennett, 1965
Cladoceran (young), *Daphnia magna*	S	U	50	7,000	5,929	Dowden & Bennett, 1965
Cladoceran (adult), *Daphnia magna*	S	U	50	21,000	17,787	Dowden & Bennett, 1965
Cladoceran, *Daphnia magna*	S	M	48	100,000	110,000	Cairns, et al. 1978
Cladoceran, *Daphnia magna*	S	M	48	92,000	101,200	Cairns, et al. 1978
Cladoceran, *Daphnia magna*	S	M	48	91,000	100,100	Cairns, et al. 1978

Table 2. (Continued)

Organism	Bioassay Method*	Test Conc.**	Time (hrs)	LC50 (ug/l)	Adjusted LC50 (ug/l)	Reference
Cladoceran, Daphnia magna	S	M	48	88,000	96,800	Cairns, et al. 1978
Cladoceran, Daphnia magna	S	M	48	91,200	100,320	Cairns, et al. 1978
Cladoceran, Daphnia pulex	S	U	48	28,000	23,716	Lee, 1976
Cladoceran, Daphnia pulex	S	M	48	93,000	102,300	Cairns, et al. 1978
Cladoceran, Daphnia pulex	S	M	48	87,800	96,580	Cairns, et al. 1978
Cladoceran, Daphnia pulex	S	M	48	85,000	93,500	Cairns, et al. 1978
Cladoceran, Daphnia pulex	S	M	48	81,000	89,100	Cairns, et al. 1978
Cladoceran, Daphnia pulex	S	M	48	79,000	86,900	Cairns, et al. 1978
Cladoceran, Daphnia pulex	R	U	48	18,000	15,246	Alekseyev & Antipin, 1976
Cladoceran, Polyphemus pediculus	R	U	48	57,000	48,279	Alekseyev & Antipin, 1976
Copepod, Cyclops vernalis	S	U	96	122,000	103,334	Anderson, et al. 1948
Copepod, Mesocyclops leukarti	S	U	96	108,000	91,476	Anderson, et al. 1948
Conchostracan, Lynceus brachyurus	R	U	48	78,000	28,408	Alekseyev & Antipin, 1976
Isopod (adult), Asellus aquaticus	R	U	48	15,000	5,463	Alekseyev & Antipin, 1976

Table 2. (Continued)

Organism	Bioassay Method*	Test Conc.**	Time (hrs)	LC50 (ug/l)	Adjusted LC50 (ug/l)	Reference
Isopod (juvenile), Asellus aquaticus	R	U	48	78,000	28,408	Alekseyev & Antipin, 1976

* S = static, R = renewal

** U = unmeasured, M = measured

Geometric mean of adjusted values = 70,549 µg/l $\frac{70,549}{21}$ = 3,400 µg/l

Table 3. Freshwater invertebrate chronic values for phenol (U.S. EPA, 1978a)

Organism	Test*	Limits (ug/l)	Chronic Value (ug/l)
Cladoceran, Daphnia magna	LC	1,500-6,300	3,074

* LC = life cycle or partial life cycle

Geometric mean of chronic values = 3,074 µg/l $\quad \frac{3,074}{5.1} = 600$ µg/l

Lowest chronic value = 3,074 µg/l

Table 4. Freshwater plant effects for phenol

Organism	Effect	Concentration (ug/l)	Reference
Alga, *Chlorella pyrenaidosa*	Complete destruction of chlorophyll in 2 days	1,500,000	Huang & Gloyna, 1968
Alga, *Chlorella vulgaris*	20% inhibition of growth in 80 hrs	470,000	Dedonder & Van Sumere, 1971
Duckweed, *Lemna minor*	Chlorosis (LC50)	1,504,000	Blackman, et al. 1955
Duckweed, *Lemna minor*	50% reduction in growth	479,400	Simon & Blackman, 1953
Diatom, *Nitzschia linearis*	50% reduction in cell production in 120 hrs	258,000	Patrick, et al. 1968
Alga, *Selenastrum capricornutum*	12% growth inhibition at 20° C	20,000	Reynolds, et al. 1973
Alga, *Selenastrum capricornutum*	27% growth inhibition at 24° C	20,000	Reynolds, et al. 1973
Alga, *Selenastrum capricornutum*	32% growth inhibition at 28° C	20,000	Reynolds, et al. 1973
Alga, *Selenastrum capricornutum*	>50% reduction of 1-day steady state cell concentration	40,000	Reynolds, et al. 1975
Alga, *Selenastrum capricornutum*	58% reduction in cell numbers in 1.92 days at 20° C	20,000	Reynolds, et al. 1975
Alga, *Selenastrum capricornutum*	66% reduction in cell numbers in 2.0 days at 24° C	20,000	Reynolds, et al. 1975

Table 4. (Continued)

Organism	Effect	Concentration (ug/l)	Reference
Alga, *Selenastrum capricornutum*	60% reduction in cell numbers in 2.26 days at 28° C	20,000	Reynolds, et al. 1975

Lowest plant value = 20,000 µg/l

Table 5. Freshwater residues for phenol

Organism	Bioconcentration Factor	Time (days)	Reference
Goldfish, *Carassius auratus*	2.0	1	Kobayashi, et al. 1976
Goldfish, *Carassius auratus*	2.0	5	Kobayashi & Akitake, 1975
Goldfish, *Carassius auratus*	1.2-2.3	5	Kobayashi & Akitake, 1975

Table 6. Other freshwater data for phenol

Organism	Test Duration	Effect	Result (ug/l)	Reference
Paramecium, Chilomonas paramecium	19-25 hrs	>50% decrease in growth from control	200,000	Cairns, et al. 1978
Paramecium Chilomonas paramecium	44-48 hrs	>50% decrease in growth from control	200,000	Cairns, et al. 1978
Paramecium, Chilomonas paramecium	98-163 hrs	>50% decrease in growth from control	200,000	Cairns, et al. 1978
Cladoceran (young), Daphnia magna	96 hrs	Immobilization (EC50)	5,000	Anderson, et al. 1948
Cladoceran (adult), Daphnia magna	96 hrs	Immobilization (EC50)	14,000	Anderson,,et al. 1948
Cladoceran, Daphnia magna	16 hrs	Immobilization	94,000	Anderson, 1944
Coho salmon (fingerling), Oncorhynchus kisutch	72 hrs	LC66.7	5,630	Holland, et al. 1960
Rainbow trout, Salmo gairdneri	114 min	50% mortality	12,200	Herbert, 1962
Rainbow trout (juvenile), Salmo gairdneri	2 hrs	Gill damage	6,500	Mitrovic, et al. 1968
Rainbow trout, Salmo gairdneri	48 hrs	Lowest concentration which killed 50% or more of the test fish	10,000	Shumway & Palensky, 1973
Brook trout (juvenile), Salvelinus fontinalis	24 hrs	Temperature selection shifted significantly downward	7,500	Miller & Ogilvie, 1975
Goldfish, Carassius auratus	8 hrs	LC62	33,300	Gersdorff, 1939
Goldfish, Carassius auratus	8 hrs	LC67	41,600	Gersdorff & Smith, 1940

Table 6. (Continued)

Organism	Test Duration	Effect	Result (ug/l)	Reference
Goldfish, *Carassius auratus*	20-30 hrs	50% mortality	40,000-100,000	Kobayashi & Akitake, 1975
Fathead minnow (adult), *Pimephales promelas*	216 hrs	Median lethal threshold concentration	27,000	Ruesink & Smith, 1975
Fathead minnow (adult), *Pimephales promelas*	122-127 hrs	Median lethal threshold concentration	22,000	Ruesink & Smith, 1975
Guppy (adult), *Poecilia reticulatus*	30 days	Increase in neuro-secratory hormone	3,120	Matei & Flerov, 1973
Bluegill, *Lepomis macrochirus*	25 hrs	50% mortality between	10,000-15,000	Dowden & Bennett, 1965
Mozambique mouthbrooder, *Tilapia mossambica*	1 mo	Manifest hemosiderosis in the spleen	2,000	Murachi, et al. 1974

Lowest value = 2,000 ug/l

SALTWATER ORGANISMS

Acute Toxicity

The data base on the effects of phenol on saltwater organisms is limited to acute toxicity tests on three fish and two mollusc species. The LC50 was 5,200 µg/l (48-hour) for rainbow trout, Salmo gairdneri, 6,014 µg/l (96-hour) for mountain bass, Kuhlia sandvicensis, and 510 µg/l (12-hour) for Stolephorus purpuratus (Tables 7 and 9). The acute toxicity of phenols to mollusc larvae was determined in two 48-hour exposures. The EC50 of phenol to hard clam larvae was 58,250 µg/l and to American oysters, 52,630 µg/l (Table 8; Davis and Hidu, 1969).

Chronic Toxicity

The chronic toxicity of phenol on saltwater plants, invertebrate and fish species has not been studied.

Miscellaneous

No data are available on the accumulation of phenol by saltwater organisms or on effects not previously discussed.

CRITERION FORMULATION

Saltwater - Aquatic Life

Summary of Available Data

The concentrations below have been rounded to two significant figures.

Final Fish Acute Value = 620 µg/l

Final Invertebrate Acute Value = 960 µg/l

Final Acute Value = 620 µg/l

Final Fish Chronic Value = not available

Final Invertebrate Chronic Value = not available

Final Plant Value = not available

Residue Limited Toxicant Concentration = not available

Final Chronic Value = not available

0.44 x Final Acute Value = 270 µg/l

No saltwater criterion can be derived for phenol using the Guidelines because no Final Chronic Value for either fish or invertebrate species or a good substitute for either value is available, and there are insufficient data to estimate a criterion using other procedures.

Table 7. Marine fish acute values for phenol (Brown, et al. 1967a)

Organism	Bioassay Method*	Test Conc.**	Time (hrs)	LC50 (ug/l)	Adjusted LC50 (ug/l)
Rainbow trout, *Salmo gairdneri*	S	U	48	5,200	2,303

* S = static

** U = unmeasured

Geometric mean of adjusted values = 2,303 µg/l $\frac{2,303}{3.7}$ = 620 µg/l

Table 8. Marine invertebrate acute values for phenol (Davis & Hidu, 1969)

Organism	Bioassay Method*	Test Conc.**	Time (hrs)	LC50 (ug/l)	Adjusted LC50 (ug/l)
Eastern oyster (embryo), Crassostrea virginica	S	U	48	58,250	49,338
Hard clam (embryo), Mercenaria mercenaria	S	U	48	52,630	44,578

* S = static

** U = unmeasured

Geometric mean of adjusted values = 46,898 µg/l $\frac{46,898}{49}$ = 960 µg/l

Table 9. Other marine data for phenol

Organism *	Test Duration	Effect	Result (ug/l)	Reference
Mountain bass, Kuhlia sandvicensis	96 hrs	LC50	6,014	Nunogawa, et al. 1970
Mountain bass, Kuhlia sandvicensis	Acute	Violent reaction	20,000	Hiatt, et al. 1953
Mountain bass, Kuhlia sandvicensis	Acute	Moderate reaction	2,000	Hiatt, et al. 1953

* Species endemic to Hawaii

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Mammalian Toxicology and Human Health Effects

Exposure

Introduction

Phenol is a high volume industrial chemical which is largely used as an intermediate for the manufacture of other chemicals. Phenol is also produced by biological processes and is a by-product of combustion and some industrial processes.

Phenol is clear, colorless, hygroscopic, deliquescent, crystalline solid at 25°C, which may become slightly pink in color as a result of impurities (Lederman and Poffenberger, 1968). The chemical and physical characteristics of phenol are presented in Table 1.

Phenol has a long history of industrial and medical uses. In 1867, Lister reported on the use of phenol sprays for disinfecting operating rooms. Today its medicinal uses are limited to a few mouth, throat, and skin medications. The industrial capacity for the production of phenol in the United States was $2,885 \times 10^6$ pounds per year in 1975 (Chem. Eng. News, 1975), about 90 percent of which was used in the production of phenolic resins, caprolactam, bisphenol-A, alkylphenols, and adipic acid (Chemical Profiles, 1972).

Table 1

Chemical and Physical Properties of Phenol
(NIOSH, 1976)

Formula:	C_6H_5OH
Molecular weight:	94.11
pK_a:	9.9
Melting point:	40-41 C
Boiling point:	181.75 C
Vapor pressure @ 25 C	0.35 mm Hg
Specific gravity: solid @ 25 C	1.071
liquid @ 25 C	1.049
Relative vapor density: (air = 1.0)	3.24
Solubility: (X = mole fraction)	Also soluble in ether,
Phenol in water: -log X =	alcohol, acetic acid,
0.375 log(66 - T) + 1.15	glycerol, liquid sul-
Water in phenol: -log X =	fur dioxide, benzene.
-0.62 log(66 - T) + 0.99	
Color:	Colorless to light pink solid
Odor:	Sweet; threshold = 1ppm
Flashpoint: open cup	85 C
closed cup	79 C
Ignition temperature:	715 C
Light sensitivity:	Darkens on exposure to light
Saturated vapor concentration (25°C)	461 ppm

It should be noted that analytical data for phenol should be interpreted with caution. Many spectrophotometric tests, specifically those following the methodologies in Deichmann's 1942 review article, are positive for phenol as well as a spectrum of substituted phenol compounds (Am. Pub. Health Assoc., 1971; Ettinger, et al. 1951; Smith, 1976).

The National Organic Monitoring Survey (U.S. EPA, 1977) reported finding unspecified concentrations of phenol in 2 out of 110 raw water supplies by GLC/MS. The Survey found no phenol in any finished water supplies. The National Commission on Water Quality (1975) reported from U.S. Geological Survey data that the annual mean concentration of phenol in the lower Mississippi River was 1.5 µg/l with a maximum of 6.7 µg/l and a minimum of 0.0 µg/l. The International Joint Commission (1978) reported finding <0.5 to 5 µg/l phenol in the Detroit river between 1972 and 1977.

Phenol is also produced endogenously in the mammalian intestinal tract through the microbial metabolism of l-tyrosine and p-hydroxybenzoic acid (Harborne, 1964). In addition, exposures to benzene (Docter and Zielhuis, 1967) and the ingestion of certain drugs (Fishbeck, et al. 1975) can lead to increased phenol production and excretion.

Ingestion from Water

During the National Organic Monitoring Survey (U.S. EPA, 1977) phenol was found in only 2 of 110 raw water supplies, as analyzed by gas-liquid chromatography and mass spectroscopy. The presence of phenol was detected but not quantified. No phenol was found in finished water supplies. The National Commission on Water Quality (1975) reported an annual mean concentration of 1.5 µg/l of phenol in raw water from the lower Mississippi River. At a water intake of 2 l/day, this would result in a phenol intake of 3 µg/person/day.

A 1974 derailment in southern Wisconsin resulted in significant groundwater contamination by phenol (Delfino and Dube, 1976; Baker, et al. 1978). Most families continued drinking their well water until it became unpalatable. The maximum concentration of phenol in the contaminated water which was actually ingested by the 39 victims is uncertain. The first tests revealed phenol concentrations of 0.21 to 3.2 mg/l in nearby wells. Concentrations in the well water eventually reached a maximum of 1,130 mg/l. Baker, et al. (1978) estimated exposures of 10 to 240 mg/-person/day in the highest exposure group. Medical histories taken six months after the spill showed a statistically significant increase in reported cases of diarrhea, mouth sores, dark urine, and burning of the mouth. Laboratory tests done at this same time for serum glutamic oxalacetic transaminase (SGOT), bilirubin, creatinine, uric acid, glucose, and cholesterol showed no significant abnormalities.

Urinary free and conjugated phenol levels, six months after each group's initial exposure, were 11.97 mg/l for the study group and 11.56 mg/l for the control group, indicating that the metabolism of dietary constituents, rather than the ingestion of contaminated water, contributed to the phenol found in the urine.

Prior to 1900, phenol was frequently ingested to commit suicide (von Oettingen, 1949). Reported lethal doses in man ranged from 4.8 to 128.0 grams (Natl. Inst. Occup. Safety Health, 1976).

Ingestion from Foods

Free and conjugated phenol is a normal constituent of animal matter (Table 2). It is most likely formed by microbial metabolism in the intestinal tract from l-tyrosine and p-hydroxybenzoic acid (von Oettingen, 1949; Harborne, 1964). There are no market basket surveys of free and conjugated phenol to allow an estimate for the daily dietary intake of phenol. Lustre and Issenberg (1970) have reported finding 7 mg/kg phenol in smoked summer sausage and 28.6 mg/kg in smoked pork belly.

Four medicinal preparations which could be expected to contribute to the ingestion of phenol are presently on the market. They are Cepastat Mouthwash, Cepastat Lozenges ((R) Merrell-National) containing 1.45 percent phenol; Chloraseptic Mouthwash, containing 1.4 percent phenol; and Chloraseptic Lozenges ((R) Eaton Laboratories), containing 32.5 mg total phenol (free phenol and sodium phenolate) per lozenge with a total manufacturer's recommended dose of up to eight

lozenges per day (Huff, 1978). Because there is no control over the intake of non-prescription drugs, some individuals may consume considerably higher doses.

TABLE 2

Phenol Content of Normal Rabbit Tissues
(6 animals)
(Deichmann, 1944)

Tissue	Phenol (mg/kg)		
	Free	Conjugated	Total
Blood	0-0.7	0-0.5	0-0.7
CNS	0	0-1.8	0-1.8
Kidney	0-1.0	0-0.5	0-1.4
Lung	0-2.3	0-3.4	0-3.4
Liver	0-0.9	1.1-5.5	1.1-6.2
Muscle	0-1.6	0-1.8	0-3.4
G.I. Tract Including Contents	0-3.0	0-2.3	0-4.4
Heart, Spleen, Thymus, Testes, Adrenals	0-0.3	0-1.0	0-1.0
Urine (24 hr/vol.)	0-3.9	11.5-100.0	11.5-100.0
Feces (24 hr)	0.4-5.3	1.4-8.0	1.8-11.7

The taste and odor of phenol, and especially some of its derivatives, are noticeable at relatively low concentrations (Table 3).

TABLE 3

Taste and Odor Thresholds for Phenol in Water

TASTE mg/l	mg/l	TEMPERATURE C	REFERENCE
>1	>1	ca.24	Burttschell, et al. 1959
	10	30	Hoak, 1957
	5	60	Hoak, 1957
1	1		Veldrye, 1972

A bioconcentration factor (BCF) relates the concentration of a chemical in water to the concentration in aquatic organisms, but BCF's are not available for the edible portions of all four major groups of aquatic organisms consumed in the United States. Since data indicate that the BCF for lipid-soluble compounds is proportional to percent lipids, BCF's can be adjusted to edible portions using data on percent lipids and the amounts of various species consumed by Americans. A recent survey on fish and shellfish consumption in the United States (Cordle, et al. 1978) found that the per capita consumption is 18.7 g/day. From the data on the 19 major species identified in the survey and data on the fat content of the edible portion of these species (Sidwell, et al. 1974), the relative consumption of the four major groups and the weighted average percent lipids for each group can be calculated:

Group	Consumption (Percent)	Weighted Average Percent Lipids
Freshwater fishes	12	4.8
Saltwater fishes	61	2.3
Saltwater molluscs	9	1.2
Saltwater decapods	18	1.2

Using the percentages for consumption and lipids for each of these groups, the weighted average percent lipids is 2.3 for consumed fish and shellfish.

Measured bioconcentration factors of 1.2 to 2.3 were obtained with goldfish by Kobayashi, et al. (1976) and Kobayashi and Akitake (1975), but the exposures only lasted one to five days. The equation "Log BCF = 0.76 Log P - 0.23" can be used (Veith, et al. Manuscript) to estimate the BCF for aquatic organisms that contain about eight percent lipids from the octanol-water partition coefficient (P). Based on an octanol-water partition coefficient of 31, the steady-state bioconcentration factor for phenol is estimated to be 8.0. An adjustment factor of 2.3/8.0 = 0.2875 can be used to adjust the estimated BCF from the 8.0 percent lipids on which the equation is based to the 2.3 percent lipids that is the weighted average for consumed fish and shellfish. Thus, the weighted average bioconcentration factor for phenol and the edible portion of all aquatic organisms consumed by Americans is calculated to be 8.0 x 0.2875 = 2.3.

Inhalation

The inhalation of phenol vapors appears to be largely restricted to the occupational environment. Phenol vapor is efficiently absorbed from the lungs. Piotrowski (1971) administered phenol vapors to human volunteers wearing masks

to minimize the effect of skin absorption. The phenol concentrations ranged from 6 to 20 mg/m^3. Piotrowski found that the retention of phenol averaged 80 percent at the beginning of the exposure but decreased to an average retention of 70 percent after eight hours of exposure. Piotrowski did not report finding any adverse effects in his subjects after the exposures to phenol vapor.

Ohtsuji and Ikeda (1972) found up to 12.5 mg/m^3 of phenol vapors in bakelite factories. They reported no adverse effects but confirmed that phenol was efficiently absorbed through the lungs.

The present threshold limit value (TLV) is 20 mg/m^3 as a time weighted average (TWA) with a ceiling value of 60 mg/m^3 (Natl. Inst. Occup. Safety and Health, 1976).

Dermal

The primary site of phenol absorption in industry is the skin. The skin is a major route of entry for phenol vapor, phenol solutions, liquid phenol, or solid phenol. Piotrowski (1971) determined that the rate of absorption of phenol vapor through the skin was similar to that through the respiratory tract. Aqueous phenol solutions (one percent w/v) readily penetrate human skin (Roberts, et al. 1977). As the phenol concentration increases the permeability coefficient also increases. At very high concentrations of phenol in water the resulting skin damage retards the absorption of phenol (Deichmann and Keplinger, 1963).

In addition to exposures from occupational sources, a number of medicinal preparations can be sources of dermally absorb-

ed phenol. A partial census of phenol-containing preparations for skin application follows. The quantities used of these agents are not under control. Campho-Phenique ((R) Glenbrook) liquid, 4.75 percent phenol, powder, 2 percent; Calamine lotion, 1 percent phenol; P&S ointment or liquid ((R) Baker Laboratories) 1 percent phenol; Panscol ointment ((R) Baker Laboratories) 1 percent phenol; Benadex ointment ((R) Fuller) 1 percent phenol; Kip for Burns ointment ((R) Young's 0.5 percent phenol; Noxzema Medicated ((R) Noxell) 0.5 percent phenol; Tanurol ointment ((R) O'Neal, Jones & Feldman) 0.75 percent phenol; Dri Toxen cream ((R) Walker Corp.) 1 percent phenol; Peterson's ointment ((R) Peterson's Ointment Co.) 2.5 percent phenol. In addition, some feminine hygiene products and hemorrhoidal products contain phenol (Huff, 1978; Am. Pharma. Assoc. 1977).

PHARMACOKINETICS

Absorption

Phenol is readily absorbed by all routes of entry. Absorption is rapid as illustrated by the fact that acutely toxic doses of phenol can produce symptoms within minutes of administration, regardless of the route of administration. Twenty-four hours after administering 300 mg/kg phenol orally to rabbits, Deichmann (1944) reported finding less than one percent of the administered dose in the feces.

Piotrowski (1971) exposed human volunteers in climate controlled inhalation chambers to phenol administered through face masks to eliminate the influence of dermal exposures.

He found that, initially, an average of 80 percent of the phenol was retained in the lungs. The percentage of retained phenol dropped during the experiment, so that after six to eight hours an average of only 70 percent of the phenol was retained in the lungs. Subsequently, Piotrowski (1971) exposed his volunteers for six to eight hours to various phenol concentrations in the exposure chamber atmosphere, while permitting them to breathe clean air through the face masks. He found that phenol vapor could be readily absorbed through the intact skin and that normal clothing provided little or no protective effect. He found that the rate of dermal absorption for phenol vapor could be represented by the formula $A=(0.35)C$, where A= amount of phenol absorbed in mg/hr, and C is the phenol concentration in mg/m^3.

When the data presented by Ohtsuji and Ikeda (1972) are recalculated utilizing the efficiency of inhalation and the skin absorption coefficient reported by Piotrowski, it can be demonstrated that the figures are confirmatory.

Distribution

Phenol is rapidly distributed to all tissues in animals that have been poisoned with the compound. Within 15 minutes of an oral dose, the highest concentrations are found in the liver, followed by heart, lungs, kidney, blood, and muscle (Table 4) (Deichmann, 1944). As time progresses, concentrations become fairly uniform and start to decrease as the body begins to clear the phenol; the concentrations of total phenol in the kidney remain relatively constant for the first six hours after oral dosing. In rabbits, roughly 77 percent of the administered dose is excreted in the urine

TABLE 4

Distribution of Phenol in the Organs of Rabbits After an Oral Dose of 0.5 g/kg (from Deichmann, 1944)

Tissue	Phenol	Died after 15 min.	Died after 82 min.	Killed after 2 hrs.	Killed after 2½ hrs.	Killed after 6 hrs.
		Concentration of Phenol in mg/kg tissue				
Liver	Free	637	224	34	135	5
	Conjugated	9	42	32	60	94
	Total	646	266	66	195	99
Blood	Free	308	224	58	113	65
	Conjugated	9	53	80	102	98
	Total	317	277	138	215	163
Kidneys	Free	353	134	48	112	26
	Conjugated	8	74	228	129	300
	Total	361	208	276	241	326
Lungs	Free	342	208	54	122	15
	Conjugated	18	47	67	51	30
	Total	360	255	121	173	45
Heart, Testes, Thymus Spleen	Free	530	210	68	140	75
	Conjugated	6	23	57	51	77
	Total	536	233	125	191	152
Brain & Cord	Free	313		68	104	25
	Conjugated	5		7	3	4
	Total	318		75	107	29
Muscle	Free	190	82	92	120	101
	Conjugated	0	5	11	8	14
	Total	190	87	103	128	115
Urine	Free		5		116	110
	Conjugated		140		520	123
	Total		145		636	233
Phenol in total air exhaled		0	1	7	1	2

during the first 24 hours and about 20 percent is completely metabolized. In summary, the distribution of phenol presents a rapid absorption phase, followed by rapid generalized distribution to all organ systems, followed by relatively rapid metabolism and excretion.

The data of Piotrowski (1971) similarly indicate a rapid rate of clearance of phenol for man, even though his study did not provide distributional data for various organs.

Metabolism

Free and conjugated phenol appear to be normal trace constituents of the human body and have also been found in other mammalian species (Harborne, 1964). Values reported for phenol concentrations in normal human blood differ markedly among various investigators. Ruedemann and Deichmann (1953) report normal blood values for free phenol at 1.5 mg/l and 3.5 mg/l for conjugated phenol. A brief list of "normal" human blood values (Natl. Inst. Occup. Safety Health, 1976) cites ranges for free phenol of none or traces to 40 mg/l and conjugated phenol concentrations of 1 to 20 mg/l. The variability appears to be due in part to the specificity of the analytical method for phenol (Ikeda and Ohtsuji, 1969), and to the amount of dietary protein which increases urinary phenol excretion (Folin and Denis, 1915). More recent values determined by gas-liquid chromatography are 0.04 to 0.56 mg/l free phenol plus 1.06 to 5.18 mg/l conjugated phenols (Dirmikis and Darbre, 1974) and 2 to 18 mg/l for total phenol (Van Haaften and Sie, 1965).

The urinary excretion of phenol can be increased above background levels by exposure to agents which are normally

metabolized to phenol, such as benzene or phenylsalicylate (Kociba, et al. 1976). The urinary excretion levels of phenol in a worker exposed to phenylsalicylate ranged from 150 to 1,371 mg/l. The ingestion of manufacturer's recommended dosages of Pepto-Bismol (contains phenylsalicylate) resulted in peak urinary phenol levels of 260 mg/l in a human volunteer (Fishbeck, et al. 1975). The normal background concentration for urinary phenol in this series was 1.5-5 mg/l by gas layer chromatography. After the ingestion of eight doses of Chloraseptic lozenges at the recommended dosing schedule, the total urinary phenol concentration peaked at 270 mg/l and the free phenol concentration peaked at 10 mg/l. When dogs were fed 125 mg phenylsalicylate/kg/day for 41 days, the peak urinary phenol concentration was 6,144 mg/l. This treatment was not associated with any reported ill effects (Kociba, et al. 1976).

The metabolism of exogenous phenol has been most clearly presented by Deichmann and Keplinger (1963) for a lethal oral dose of 0.5 g/kg in rabbits and for a sublethal oral dose of 0.3 g/kg in rabbits. These studies are summarized in Figures 1 and 2.

There are some species differences in the metabolism of phenol. Capel, et al. (1972) reported that man, rat, mouse, jerboa, gerbil, hamster, lemming, and guinea pig excreted four major metabolites: sulfate and glucuronic acid conjugates of phenol and 1,4-dihydroxybenzene; the squirrel monkey and the capuchin excreted phenyl glucuronide, 1,4-dihydroxybenzene glucuronide, and phenyl sulphate. The ferret, dog, hedgehog, and rabbit excreted phenyl sulfate,

1,4-dihydroxybenzene sulfate, and phenyl glucuronide. The rhesus monkey, fruit bat, and chicken excreted phenyl sulfate and phenyl glucuronide, but no 1,4-dihydroxybenzene conjugates. The cat appeared to excrete only phenyl sulfate and 1,4-dihydroxybenzene sulfate, and the pig was found to excrete phenylglucuronide as its major metabolite of phenol. The doses in this study were relatively low. Miller, et al. (1976) demonstrated that the cat was sensitive to phenol, and that in addition to sulfate conjugates, free 1,4-dihydroxybenzene was a major metabolite, possibly accounting for the toxicity in the cat. The authors also noted that the metabolic pattern was dose dependent. Oehme and Davis (1970) found that except for cats, the rate of phenylglucuronide excretion increased progressively with the dose so that at high doses phenylglucuronide formation predominated over phenyl sulfate formation.

In man, the rate of absorpancy, metabolism and excretion of phenol is relatively rapid. The absorbed phenol was almost completely metabolized and excreted within 24 hours in inhalation experiments near the TLV (Piotrowski, 1971).

Excretion

In man and all mammals that have been tested, nearly all of the phenol and its metabolites are excreted in the urine. Only minor amounts are excreted in air and in the feces (Figures 1 and 2). Piotrowski (1971) studied the excretion of phenol in human volunteers that had been exposed

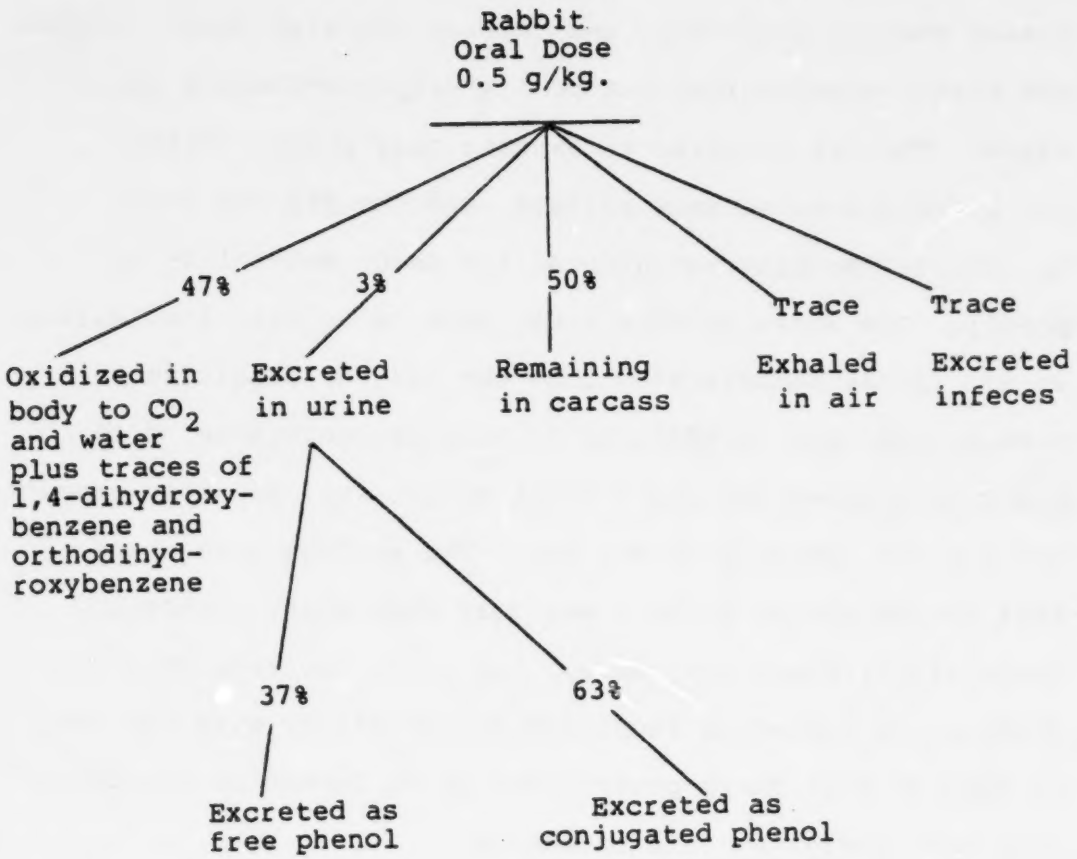

Figure 1. Fate of a lethal oral dose of phenol analyzed over 5 hours (Deichmann, 1942)

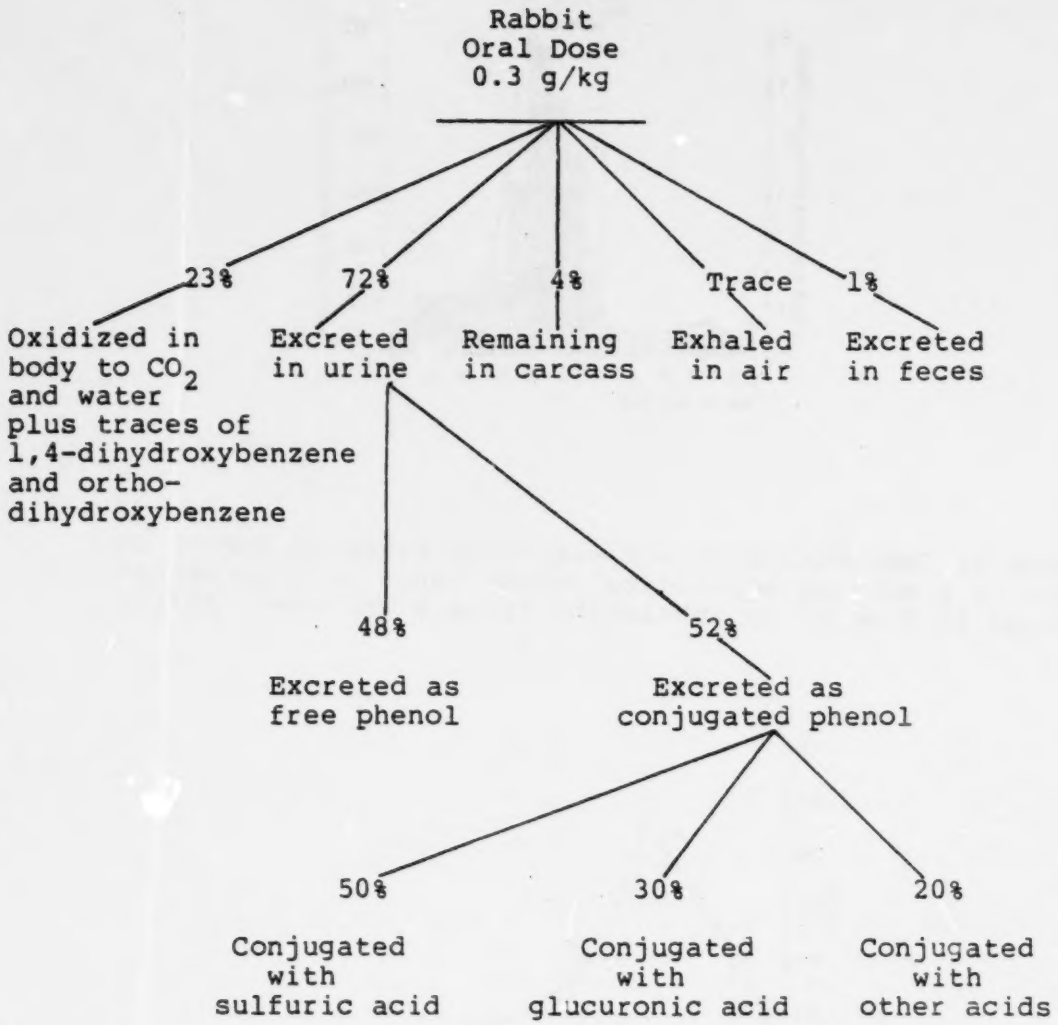

Figure 2. Fate of a sublethal oral dose of phenol analyzed over 24 hours (Deichmann, 1942)

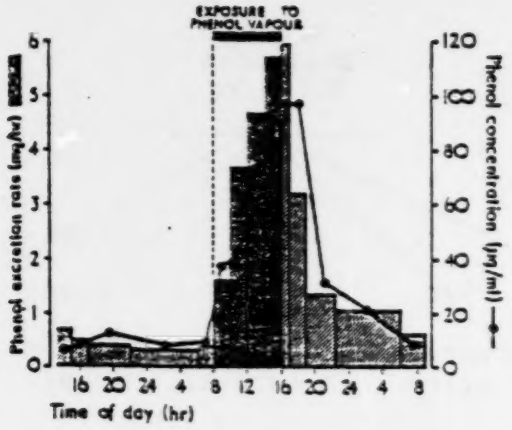

Figure 3: Concentrations and excretion rates of phenol in urine in a subject exposed to phenol vapor in a concentration of 18.3 mg/m^3 by inhalation (from Piotrowski, 1971).

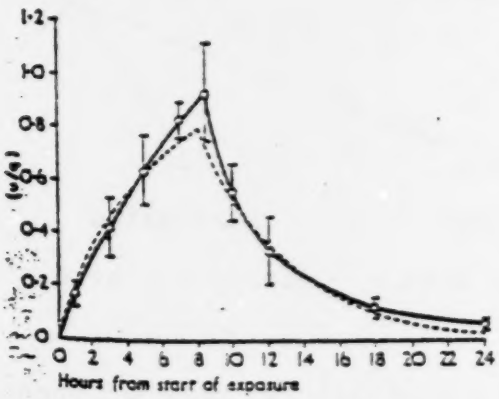

Figure 4: Excretion rate of "excess phenol in relation to absorption. Means $\pm$ S.D. Dotted line - theoretical curve for K=0.2 hour^{-1}. (From Piotrowski, 1971).

to phenol through inhalation or skin absorption. He found that the human body behaved almost like a single compartment with respect to phenol absorption and clearance, with an excretion rate constant of K=0.2 hrs.$^{-1}$. This corresponds to a half life of approximately 3.5 hours (Figures 3 and 4). The half life is defined as $t_{\frac{1}{2}} = \frac{0.693.}{K}$

EFFECTS

Acute, Sub-acute, and Chronic Toxicity

Regardless of the route of administration, the signs and/or symptoms of acute toxicity in man and experimental animals are similar. The predominant acute action of a toxic dose in man appears to be on the central nervous system leading to sudden collapse and unconsciousness. In some mammalian species these effects are initiated by muscular twitchings and severe convulsions. The USSR literature reference in the National Institue for Occupational Safety and Health phenol criterion document reported finding changes in sensitivity to light after five minute exposures at 15.5 $\mu g/m^3$ and changes in the formation of conditioned reflexes at 15.5 $\mu g/m^3$.

After the absorption of an acutely toxic dose the heart rate first increases and then becomes slow and irregular. After an initial rise, the blood pressure falls significantly. Salivation may be evident. There is usually a slight fall in body temperature, and a marked depression in respiration occurs. Death may occur within minutes of the acute exposure and is usually due to respiratory arrest (Deichmann and Keplinger, 1963; Sollmann, 1957). The approximate median lethal doses (LD_{50}) for phenol in various species dosed

by several different routes are listed in Table 5. It can be noted that most of the data fall within one order of magnitude. The cat seems to be the most sensitive species, which seems to be a consequence of its metabolism of phenol. It is difficult to estimate the LD_{50} of oral phenol for man, even though phenol has a long history of use in suicidal attempts. A series of human data is presented in Table 6. Dosages were calculated assuming a bodyweight of 70 kg.

When the data in Tables 5 and 6 are compared, it becomes evident that man is not unusually sensitive to the acute effects of phenol when compared to other mammalian species.

Deichmann and Keplinger (1963) describe the following pathological changes associated with acute exposures to phenol:

> The pathological changes produced by phenol in animals vary with the route of absorption, vehicle employed, concentration, and duration of exposure. Local damages to the skin include eczema, inflammation, discoloration, papillomas, necrosis, sloughing, and gangrene. Following oral ingestion the mucous membranes of the throat and esophagus may show swelling, corrosions, and necroses, with hemorrhage and serious infiltration of the surrounding areas. In a severe intoxication the lungs may show hyperemia, infarcts, bronchopneumonia, purulent bronchitis, and hyperplasia of the peribronchial tissues. There can be myocardial degeneration and necrosis. The hepatic cells may be enlarged, pale, and coarsely granular with swollen, fragmented, and pyknotic nuclei. Prolonged administration of phenol may cause parenchymatous nephritis, hyperemia of the glomerular and cortical region, cloudy swelling, edema of the convoluted tubules, and degenerative changes of the glomeruli. Blood cells become hyaline, vacuolated, or filled with granules. Muscle fibers show marked striation.

TABLE 5

The Acute Toxicity of Phenol to Non-human Mammals[a]

Species	Route	Dose killing approx. 50% g/kg	Reference
Cat	Subcut.	0.09	Tollens, 1905
Cat	Oral	0.1	Macht, 1915
Dog	Oral	0.5	Macht, 1915
Guinea Pig	Subcut.	0.68	Duplay & Cazin, 1891
Mouse	Subcut	0.3	Tollens, 1905
Rabbit	Intrav.	0.18	Deichmann & Witherup, 1944
Rabbit	Subcut.	0.5-0.6	Tauber, 1895; Tollens, 1905
Rabbit	Oral	0.6	Clarke & Brown, 1906
Rabbit	Oral	0.4-0.6	Deichman & Witherup, 1944
Rabbit	I.P.	0.5-0.6	Deichmann & Witherup, 1944
Rat	Subcut.	0.45	Deichmann & Witherup, 1944
Rat	Oral	0.53	Deichmann & Witherup, 1944
Rat	Oral	0.34 (20% Emuls.)	Deichmann & Witherup, 1944
Rat	I.P.	0.25 (in olive oil)	Farquharson, et al. 1958
Rat	Dermal	2.5	Deichmann & Witherup, 1944
Rat	Dermal	0.67	Conning & Hayes, 1970

[a] in dilute aqueous solution, unless noted otherwise.

TABLE 6

Oral Toxicity of Phenol in Humans

Total Dose g	Estimated[b] g/kg	Effect	Reference
5	0.07	Survived	Willhard, 1886
10-20	0.14-0.29	Died	Stajduhar-Caric, 1968
15	0.21	Survived	Model, 1889
15	0.21	Died	Kronlein, 1873
25-30	0.36-0.43	Died	Geill, 1888
50	0.71	Survived	Geill, 1888
53	0.75	Survived	Bennett, et al. 1950

[b] assuming a 70 kg bodyweight.

In addition, the urine is usually dark or "smoky" in appearance, probably due to oxidation products of phenol. The urine may darken further upon standing (Sollmann, 1957).

The symptoms reported by humans that had consumed phenol contaminated groundwater for approximately one month (Baker, et al. 1978) are summarized in Table 7. The daily dose of phenol consumed was estimated to be 10 to 240 mg.

TABLE 7
Symptom Distribution of Cases and Controls After Ingestion of Well Water Contaminated by Phenol (Baker, et al. 1978)

Symptom (N = 39)	Percentage of Individuals with Study Group (N = 119)	Control Group
Vomiting	15.4	13.9
Diarrhea	41.0	13.5
Headache	23.1	16.1
Skin rash	35.9	22.6
Mouth sores	48.7*	12.6
Paresthesia or numbness	13.2	8.4
Abdominal pain	23.1	11.8
Dizziness	21.1	9.3
Dark urine	17.9	3.4
Burning with urination+	10.3	10.0
Fever+	15.4	10.9
Back pain	20.5	11.0
Burning mouth	23.1*	6.8
Shortness of breath	10.3	6.7

*Significantly greater than controls, P .01, Fishers Exact test.
+Not associated with phenol exposure in previous medical reports.

Deichmann and Oesper (1940) administered phenol to rats in their drinking water for 12 months at 0, 800, 1,200, 1,600, 2,000, and 2,400 mg/l. This corresponded to an average daily intake of 0, 21, 30, 49, 56, and 55 mg of phenol per rat per day based on actual water consumption data. At the end of the experiment there were no significant differences in tissue phenol levels of the control and experimental rats. The weight gain of the rats at the two highest dose levels was depressed. A daily oral dose of 56 mg per rat is approximately 30 percent of the single oral dose required to kill a large proportion of rats in a short time. An additional indication of the rapid metabolism of phenol is demonstrated by the fact that the rats that ingested the highest daily amount consumed, over a one-year period, the equivalency of approximately 120 LD_{50} oral doses.

Heller and Pursell (1938) fed phenol to rats in their drinking water over several generations. The results of their experiment are listed in Table 8, below.

TABLE 8

The Effect of Phenol Solutions Upon Rats
(Heller and Pursell, 1938)

Phenol Drinking Solutions mg/l	Growth	Reproduction	Comments
100	Normal	5 generations	Splendid condition
500	Normal	5 generations	Appearance good
1,000	Normal	5 generations	Food & water intake satisfact.
3,000	Normal	3 generations	General appearance good
5,000	Normal	3 generations	General appearance good
7,000	Below normal	2 generations	Stunted growth in young
8,000	Fair	2 generations	Many young died
10,000	Retarded	Retarded	Young not cared for
12,000	Retarded	None	Old died in hot weather

In an unpublished study by Dow Chemical Company (1976) rats were fed 20 daily doses of 0.1 g/kg phenol by gavage. These rats showed slight liver and kidney effects, while rats which received 20 daily doses of 0.05 or 0.01 g/kg phenol demonstrated none of those effects. In a subsequent series of tests, rats received 135 doses of 0.1 or 0.05 g/kg phenol by gavage over a six month period. The growth of the rats was comparable to that of the controls. Very slight liver changes and slight to moderate kidney damage were seen in the rats which had received 0.1 g/kg phenol. The feeding of 0.05 g/kg of phenol resulted only in slight kidney damage.

In a 41-day feeding study Kociba, et al. (1976) fed 125 mg phenylsalicylate/kg/day to beagle dogs. Since phenylsalicylate is metabolized to phenol, this resulted in urinary phenol levels up to 6,144 mg/l. This high level of phenol excretion was not associated with any discernible ill effects in the dogs. Repeated exposures to phenol at high concentrations have resulted in chronic liver damage in man (Merliss, 1972).

Synergism and/or Antagonism

No significant evidence could be found to support the occurrence of synergistic or antagonistic actions of phenol with other compounds in mammals.

Challis (1973) reported that phenol could react rapidly with nitrites *in vitro* to produce p-nitrosophenol.

Teratogenicity

The work by Heller and Pursell (1938) which has been discussed previously, demonstrated no significant effects on reproduction in rats receiving 100 to 5,000 mg/l phenol in their drinking water over three to five generations. This study was, however, not designed specifically as a teratogenicity study.

Mutagenicity

Demerec, et al. (1951) reported that phenol produced back-mutations in E. coli from streptomycin dependence to non-dependence. Significant back-mutations occurred at 0.1 to 0.2 percent phenol concentrations. However, at these concentrations the survival of bacteria was only 0.5 to 1.7 percent. Dickey, et al. (1949) found phenol to be non-mutagenic for Neurospora. Hadorn and Niggli (1946) found phenol mutagenic in Drosophila after exposing the gonads of Drosophila to phenol in vitro.

The existing information on the mutagenicity of phenol is equivocal and needs to be reexamined through the use of better established methodologies.

Carcinogenicity

Boutwell and Bosch (1959) tested the tumor promoting activity of phenolic compounds in various strains of mice that had been exposed to a single dose of the initiator 9,10-dimethyl-1,2-benzanthracene (DMBA) by skin painting followed by repeated dermal applications of selected phenols. In one experiment in this series, mice which had been specially inbred for sensitivity to develop tumors, after initiation with DMBA and promotion by croton oil through skin

painting, received a single application of 75 µg DMBA to the clipped skin. This was followed one week later by twice weekly applications of 2.5 mg phenol applied to the skin as a ten percent solution in benzene repeatedly for 42 weeks. The mice receiving this dose and concentration of phenol exhibited severe skin damage, decreased body weight, and increased mortality. After 13 weeks 22 out of 23 mice had developed papillomas and 73 percent had developed carcinomas. In a group of mice which were treated with DMBA only, 3 out of 21 survivors exhibited papillomas after 42 weeks. In a group exposed to twice-weekly skin paintings with 10 percent phenol alone, 5 out of 14 survivors had papillomas (36 percent) after 52 weeks. The skin painting with phenol was continued until the 72nd week at which time one fibrosarcoma was diagnosed. Other strains of mice, Holtzman, CAF_1, and C3H, also produced papillomas after initiation with DMBA and subsequent skin painting with ten percent phenol, but the incidence was lower. The same schedule of application of 1.25 mg phenol twice weekly to Rusch's special breed of Sutter mice resulted in a lower incidence of papillomas and carcinomas. No carcimomas occurred in the standard breeds of mice when exposed to phenol without pre-treatment with DMBA. Tests with a 20 percent phenol solution (5 mg/mouse) caused a number of deaths due to systemic toxicity.

Salaman and Glendenning (1957) reported that "S" strain albino mice showed strong promoting activity for tumor formation after initiation with 0.3 mg DMBA followed by repeated skin applications of 20 percent phenol. Twenty percent phenol solutions produced significant damage to the skin

and were mildly carcinogenic when applied alone. Phenol in a five percent solution had a moderate promoting effect but was not carcinogenic without previous initiation.

VanDuuren, et al. (1971) found phenol (3mg/mouse, 3x/week) in ICR/Ha Swiss mice to have only slight promoting activity after initiation with benzo(a)pyrene (BaP). In subsequent experiments VanDuuren, et al. (1973) demonstrated that phenol is not cocarcinogenic since, when it is applied together with BaP repeatedly, tumorogenesis is inhibited slightly. This partial inhibitory effect in cocarcinogenesis experiments was subsequently confirmed by VanDuuren and Goldschmidt (1976).

In conclusion, phenol appears to have tumor promoting activity in many strains of mice when repeatedly applied to the clipped skin after initiation with known carcinogens. The tumor-promoting activity is highest at dose levels of phenol which have some sclerosing activity but also occurs in sensitive strains at phenol concentrations which do not produce obvious skin damage. Phenol has no cocarcinogenic activity when applied simultaneously and repeatedly together with BaP to mouse skin, but it reduces the incidence of tumor formation slightly. Phenol has carcinogenic activity when applied repeatedly to the skin of a specially bred strain of Sutter mice, especially at concentrations which produce repeated skin damage. Phenol has not been found to be carcinogenic when applied alone to the skin of standard strains of mice.

While the existing qualitative data derived from skin painting in one sensitive strain of mice provide weak suspicion for a carcinogenic response to phenol, the protocol was found, in agreement with NIOSH, to be inappropriate and inadequate for the purpose of judging phenol to be a carcinogen in drinking water.

CRITERION FORMULATION

Existing Guidelines and Standards

In 1974, the Federal standard for phenol in air in the workplace was 19 mg/m^3 or 5 ppm as a time weighted average (39 FR 125). This coincided with the recommendation of the American Council for Governmental Industrial Hygienists (1977). The NIOSH (1976) criteria for a recommended standard for occupational exposure to phenol are 20 mg/m^3 in air as a time weighted average for up to a ten hour work day and a 40-hour work week, with a ceiling concentration of 60 mg/m^3 for any 15-minute period.

The U.S. EPA interim drinking water limit for phenol is 0.001 mg/l, which is largely an aesthetic standard based on the objectionable taste and odor produced by chlorinated phenols. In response to a phenol spill in Southern Wisconsin, the U.S. EPA proposed on November 26, 1974 an emergency standard of 0.1 mg phenol/l as being temporarily acceptable for human consumption (Baker, et al. 1978).

Current Levels of Exposure

The National Organic Monitoring Survey (U.S. EPA, 1977) reported finding unspecified concentrations of phenol in 2 out of 110 raw water supplies. The Survey found no phenol in any finished water supplies. The National Commission on Water Quality (1975) reported that the annual mean phenol concentration in the lower Mississippi River was 1.5 µg/l in 1973, with a maximum of 6.7 µg/l.

Endogenously produced phenols in man occur at significantly higher concentration than this. They result in total urinary free and conjugated phenol concentrations ranging from 5 to 55 mg/l.

Occupational exposures at a TLV of 20 mg/m^3 TWA would result in the absorption of 105 mg phenol from the inspired air, assuming moderate to low activity (7 m^3 air breathed per 8 hours), and an absorption efficiency of 75 percent. During heavier activity (equivalent to 20 m^3/8 hours) the absorption would rise to 300 mg phenol for an eight hour shift. The additional skin absorption would be expected to substantially increase these quantities.

Special Groups at Risk

In 1976, NIOSH estimated the number of people who may be exposed to phenol at 10,000. This reflects the number of people that are employed in the production of phenol, formulation into products, or distribution of concentrated products. In addition, an uncertain but probably large number of people will have intermittent contact with phenol as components of medications or in the workplace as chemists, pharmacists, biomedical personnel, and other occupations.

Basis and Derivation of Criterion

Heller and Pursell (1938) reported no significant effects in a multi-generation feeding study in rats at 100, 500, and 1,000 mg/l of phenol in drinking water for five generations and at 3,000 and 5,000 mg/l for three generations. Assuming a daily water intake of 30 ml and an average body

weight of 300 grams, these rats would have received daily doses of 10, 50, 100, 300, and 500 mg/kg/day. The upper range approaches a single LD_{50} dose per day. Deichmann and Oesper (1940) reported no significant effects in rats receiving approximately 70, 100, or 163 mg/kg/day in their drinking water for 12 months. However, both of these studies did not report detailed pathological or biochemical studies but relied mostly on the weights and the general appearance of the animals for evaluation. In a more recent study (Dow Chem. Co., 1976), 135 dosings by gavage over six months at 100 mg/kg/dose resulted in some liver and kidney damage. At 50 mg/kg/dose the exposure resulted in only slight kidney damage. It must be borne in mind that in the first two studies the phenol is incorporated into the drinking water so that the daily dose is taken gradually. In the Dow study the phenol is administered in a single slug. A 500-fold uncertainty factor applied to the 50 mg/kg exposure in the Dow study would provide an estimated acceptable level of 0.1 mg/kg/day for man. In the case of phenol a great deal of information on human exposure exists. Long-term animal data are available as well, however, the detail in these studies is very incomplete. Shorter term studies of sufficient detail provide the lowest dose level in animal studies for which an adverse effect was seen. It was judged that the existing data did not fully satisfy the requirements for the use of a 100X uncertainty factor but were better than the requirements for a 1,000X uncertainty factor (Table 9). Consequently, an intermediate 500X uncertainty factor was selected.

TABLE 9

Guidelines for Using Uncertainty Factors
(NAS Drinking Water and Human Health, 1977)

Uncertainty Factor = 10	Valid experimental results from studies on prolonged ingestion by man, with no indication of carcinogenicity.
Uncertainty Factor = 100	Experimental results of studies of human ingestion not available or scanty (e.g., acute exposure only).
	Valid results of long-term feeding studies on experimental animals or in the absence of human studies, valid animal studies on one or more species.
	No indication of carcinogenicity.
Uncertainty Factor = 1,000	No long term or acute human data. Scanty results on experimental animals.
	No indication of carcinogenicity.

When one examines the amount of phenol absorbed through inhalation near the TLV of 20 mg/m^3 for occupational exposures by using the Stokinger and Woodward model (1958), then at a breathing rate of 10 m^3 for an eight hour day with 75 percent absorption and a body weight of 70 kg, a man would absorb approximately 2.14 mg/kg/working day, assuming no skin absorption. The use of the Stokinger-Woodward model may be applicable to estimate acceptable intake from water.

It has been established that phenol is absorbed rapidly by all routes and subsequently is distributed rapidly. If a tenfold safety factor is applied to the projected doses absorbed from inhalation at the TLV (which already incorporates some safety factors), then the projected acceptable level would be 0.2 mg/kg/day. The estimate from animal data is 0.1 mg/kg/day. On the basis of chronic toxicity data in animals and man, an estimated acceptable daily intake for phenol in man should be 0.1 mg/kg/day or 7.0 mg/man, assuming a 70 kg body weight. Therefore, assuming 100 percent gastrointestinal absorption of phenol, and consuming 2 liters of water daily and 18.7 grams of contaminated fish having a bioconcentration factor of 2.3, would result in a maximum permissible concentration of 3.4 mg/l for the ingested water:

The equation for calculating the criterion for the phenol content of water given an Acceptable Daily Intake is

$$2X = (0.0187)\ (F)\ (X) = ADI$$

Where

2 = amount of drinking water, liter/day

x = phenol concentration in water, mg/l

0.0187 = amount of fish consumed, kg/day

F = bioconcentration factor, mg phenol/kg fish per mg phenol/l water

ADI = limit on daily exposure for a 70 kg person

$$2X + (0.0187)\ (2.3)X = 7.0$$

$$X = 3.4 \text{ mg/l}$$

This water quality criterion is in the range of reported taste and odor threshold values for phenol reported in Table 3. It must be noted that this value has been derived for unchlorinated phenol.

It is recognized that when ambient water containing this concentration of phenols is chlorinated, various chlorinated phenols may be produced in sufficient quantities to produce objectional taste and odors (See Introduction). 2-Chlorophenol and 2,4-dichlorophenol have been reported to exhibit a threshold of unfavorable odor in water at concentrations of 0.33 ug/l and 0.65 ug/l, respectively. Consequently, criteria of 0.3 ug/l and 0.5 ug/l were published in the Federal Register on March 15, 1979 (44 FR 15926), for these two chlorophenols.

In view of the fact that the organoleptic properties of phenol may be greatly potentiated through the inadvertent chlorination of phenol-contaminated water, the phenol concentration in water should not exceed 1.0 ug/l in those instances where such inadvertent chlorination may take place.

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In summary, based on the use of chronic toxicologic test data for rats and an uncertainty factor of 500, the criterion for phenol corresponding to the calculated acceptable daily intake of 0.1 mg/kg/day is 3.4 mg/l. Drinking water contributes 98 percent of the assumed exposure while eating contaiminated fish products accounts for two percent. The criterion level could alteratively be expressed as 163 mg/l if exposure is assumed to be from the consumption of fish and shellfish products alone.

Based on the potential chlorination of phenol in water, the criterion for phenol is 1.0 ug/l in those instances where such inadvertent chlorination may take place.

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GPO 943-114